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EFFECTS OF HYDRAULIC RESISTANCE CIRCUIT TRAINING ON PHYSICAL FITNESS COMPONENTS RELEVANT TO $+G_z$ TOLERANCE

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ABSTRACT

Recent studies carried out in the United States and Sweden have demonstrated that strength training can improve $+G_z$ acceleration tolerance. Therefore the CF Directorate of Physical Education, Recreation and Amenities has designed a training program which has recently been introduced for aircrew of high performance aircraft. This report describes the changes in physical fitness components considered relevent to $+G_z$ tolerance after 12 weeks of training with this program. Forty-five military personnel were tested prior to beginning training. Only 20 subjects completed a minimum of 24 training sessions during the 12 weeks; these twenty were retested in order to evaluate the effects of adherence to the program. The following variables were measured prior to and after training: maximal strength of several large muscle groups during isokinetic contractions, maximal aerobic power and an index of endurance fitness, maximal anaerobic power, anthropometric characteristics, and maximal expiratory pressure generated by the respiratory muscles during exhalation. Training involved hydraulic resistance circuit training 2-4 times/week. The circuit consisted of performing three consecutive sets at each of eight stations using Hydra-Gym equipment. The exercise:rest ratio was 20:40 seconds for the initial four training weeks and was then changed to 30:50 seconds. After training the changes in anthropometric measurements suggested that lean body mass was increased. Significant increases were also measured in muscle strength during bench press, biceps curls, squats, knee extension and flexion. These increases were small when compared to relative increases in strength reported previously in the literature. Neither maximal anaerobic power (i.e. muscular endurance) nor maximal expiratory pressure were changed after the training. The indices of endurance fitness were also significantly increased in the present study. It is suggested that the small increases in strength are probably due to the design of the exercise:rest ratio which resulted in improved strength and aerobic fitness. Other studies suggest that combined strength and endurance training reduces the rate of strength increase usually found when engaging in only strength training. Therefore it is recommended that the available training time be used to concentrate on increasing muscle strength, if the prime objective is to enhance physical fitness components relevant to $+G_z$ tolerance.

BACKGROUND

The results of recent studies carried out in the United States (1) and Sweden (2) suggest that increasing muscular strength can significantly increase the ability to withstand $+G_z$ acceleration forces during simulated aerial combat maneuvers (SACM) in a human centrifuge. The increases reported could theoretically enhance the potential of aircrew to utilize the maximum operational charactistics of high performance aircraft. These characteristics presently enable certain aircraft to structurally withstand $+G_z$ forces in excess of human tolerance limits (3).

In view of the possible benefits of strength training in improving human performance during $+G_z$ force exposure, strength training programs have been instituted by the CF Directorates of Preventive Medicine (DPM 6681-1 SURG OPS 26 Jun 84), and Physical Education, Recreation and Amenities (DPERA) (4816-2-1 DPERA2 07 Dec 84) at all bases where the CF-18 is presently, or will be, in service.

The Applied Physiology Section, Biosciences Divison, at DCIEM was requested by DPERA (4816 -1 DPERA 2-2 7 May 84) to evaluate the effects of adherence to the training program on selected physiological and physical fitness components. This report describes the changes in these components in subjects who adhered to the program for 12 consecutive weeks.

METHODS

Subjects. All subjects were volunteers from personnel at CFB Moose Jaw. Forty-five subjects volunteered to participate in the study and were tested prior to beginning training. Table 1 shows that most of the subjects were aircrew, more specifically jet flight instructors, while the remainder were flight control and clerical personnel.

It was decided that only those subjects who completed an average of two training sessions per week during the 12 weeks of training would be included in the analysis of the collected data. Twenty (2 females, 18 males) of the original 45 subjects met this criterion and only their test data have been included in the analysis and discussion of this report.

None of the subjects could be classified as an elite athlete although several were engaged in recreational sports activities regularly. All subjects were asked to maintain their routine activities involving physical exertion for the duration of the study.

Testing. The testing phases occurred within one week before training commenced and one week after the subjects completed their last training session, i.e. 21-24 January and 29 April-2 May 1985, respectively. All tests were performed on the same day in two phases with approximately 2.5 hours of uncontrolled recovery between the phases.

Phase I:

Muscular strength. Muscular strength of selected muscle groups was evaluated on the Ariel Computerized Exercise (ACE) apparati. Documentation of the reliability and validity of the ACE has been reported previously (4). This equipment was used to measure force or torque production during maximum voluntary isometric and/or isokinetic contractions. After a warm-up of the muscle group to be tested, three maximal contractions were performed. If the force measured during the third contraction was more than 10% greater than either of the other contractions, the procedure was repeated. The following exercises were performed:

(a) supine bench press on the ACE Multi-Function (MF) apparatus (Fig. 1) with the lever-arm controlled to move isokinetically at both relatively slow (10 °/s) and fast (45 °/s) velocities (note: the angular velocities refer to the velocity of the ACE lever-arm, not necessarily

the anatomical levers);

(b) standing squats (knee extension) on the ACE MF (Fig. 2) at the same two velocities used for the bench press;

(c) biceps curls (elbow flexion) (Fig. 3) at the velocities described above as well as isometrically with the inner elbow angle at 90°;

(e) sitting unilateral knee extension and flexion (Fig. 4) at relatively slow (30°/s), intermediate (100°/s) and fast (200°/s) velocities on the ACE Arm-Leg (AL) apparatus, and isometric extension with the knee at 90° of flexion.

Lactate response to exercise. Aerobic capacity was evaluated by having all subjects perform five min acute exercise on a mechanically braked cycle ergometer (Cardionics) at 60 revolutions/min with a constant power output of 194 W for the males and 94 W for the females. Blood was sampled (20 μl) from the fingertip immediately after exercise and subsequently assayed for lactic acid concentration (5). A validation of the specific protocol used to evaluate the aerobic component of physical fitness in this study is described in detail elsewhere (6). Several recent studies have demonstrated that the capacity for endurance exercise is more closely related to blood lactate related variables than to VO_2max (see ref. 7 for recent review).

Muscular endurance and anaerobic power. These components were evaluated by performance of the Wingate Test. The test consisted of pedalling at maximal frequency for 30 s against a resistance of either 75 g/kg body weight, for the males, or 65 g/kg body weight, for the females. A mechanically braked cycle ergometer (Cardionics) was used in which one pedal revolution caused a 6 m progress at the perimeter of the flywheel. For every 1/3 pedal revolution, an impulse was

received by a pre-programmed calculator which printed out the average power output (in W) for every 5 s period during the duration of the test. Performance variables calculated were: peak power - the highest power output during any of the 5 s periods; mean power generated during the 30 s; a fatigue index - the final 5-s power output/peak power x 100.

Maximal expiratory pressure. While wearing noseclips, subjects exhaled as rapidly and forcefully as possible into a stainless steel cylinder. The cylinder was connected via rubber tubing to an anaeroid sphygmomanometer indicator which was calibrated from 0 - 300 mm Hg. The peak pressure developed during each of 5-10 trials was recorded. Typically, a maximal peak pressure would be recorded after which lower values were recorded on subsequent trials. The highest recorded peak pressure was considered as the maximal expiratory pressure. This procedure is outlined in greater detail elsewhere (8).

Phase II:

Maximal aerobic power (VO_2max). VO_2max was determined on a mechanically braked cycle ergometer (Monark) with a continuous, incremental protocol. The pedalling frequency was 75 revolutions/min and power output was increased by 37 W/min until volitional termination or exhaustion. Expired gases were continuously directed into a Beckman Metabolic Cart where the mean oxygen uptake (VO_2) was automatically calculated for each 30 s period. The peak VO_2 measured was considered to be the VO_2max. As another indicator of maximal aerobic power, the highest power output that could be maintained at the prescribed pedalling rate, i.e. 75 revolutions/min, for a full minute was also recorded. This variable will be referred to as the maximal aerobic power (MAP) load.

Anthropometric measurements. Measurements were performed on subjects wearing bathing suits. Heights and weights were recorded with a standard medical

scale. All limb circumferences and skinfolds were taken on the right side of the body while the subjects stood relaxed with heels together. The following circumferences were measured with a cloth tape: neck, shoulders, chest, upper arm with relaxed biceps, upper arm with contracted biceps, forearm, abdomen, thigh, calf, wrist, hip, knee, and ankle. The following skinfold thicknesses were measured using Harpenden calipers: biceps, triceps, subscapular, suprailiac, anterior thigh, abdomen, and calf. A detailed description of the measurement procedures is found in Behnke and Wilmore (9).

The subjects were then immersed in a swimming pool and standard methods (10) were employed to carry out hydrostatic weighing. Residual volume was predicted from age and direct measurement of forced vital capacity (11). Body density was calculated from the hydrostatic weighing and substituted into the equation of Siri (12) for estimation of percent body fat. Lean body mass (LBM) was calculated by subtracting the calculated weight of body fat from the measured body weight.

Training. The training program was prescribed by DPERA and is identical to that described by Lee (19). Subjects were asked to train 3-5 days weekly. The training was performed as interval circuit training, consisting of eight exercise stations utilizing Hydra Gym hydraulic resistance equipment. The equipment provides a variable, isokinetic-like resistance throughout the range of motion. The valve settings of the hydraulic cylinders can be adjusted to vary the resistance. The valves have six steps, ranging from numbers '1' through '6', which change the aperture size through which hydraulic fluid is forced as the lever arm moves; the faster the lever arm is moved, the greater the resistance becomes. The training equipment consisted of a four-station central unit and four separate stations placed about the training room, which was located inside an aircraft hangar at CFB Moose Jaw.

The following stations, specific to Hydra-Gym equipment, were included in the training circuit: jump squat, neck machine front/back, bench press/row, biceps/triceps, neck machine side/side, bilateral quadriceps/hamstring, shoulder press/ lat pull, and upright row/triceps extension. At the first session the subjects started at the station of their choice, and progressed through the circuit in the order described above. At each subsequent workout they started at the station after the one where they started during the previous workout.

The subjects trained in pairs and completed three sets at each station. The work-rest times were measured with an electronic timer which signalled the start and stop of exercise. During the first four weeks of training the subjects were required to complete as many repetitions as possible of each exercise in 20 s, with forty seconds of rest intervening between sets. After week four the subjects were asked to complete as many repetitions as possible of each exercise in 30 s, followed by 50 s of rest.

For the first training session, the valve setttings were placed at '1', '5', and '3' for the first, second, and third sets, respectively. If the number of repetitions completed in a given set met or exceeded the limits shown in Annex A, the cylinder setting for that set was increased by one step for the next training session. After week four when the work:rest ratio was changed to 30:50 s, the cylinder settings were returned to '1', '5', and '3' for the three consecutive sets, and resistance was increased as described above and shown in Annex A.

Prior to beginning each training circuit, subjects participated in a 2 min warm-up period, consisting of stretching and calisthenic exercises. A cool-down period of 5 min duration was allowed after each circuit.

Statistical analyses. The BMDP statistical software package (13) was used to evaluate the significance of the differences between the mean pre-training and post training results on the performance tests. Student's t-test for dependent

observations was used with statistical significance set at the 0.05 level.

RESULTS

Subjects. The fact that 25 of the original 45 subjects did not complete an average of two workouts/week was examined in light of the initial fitness levels of the subjects. The 45 subjects were divided into two groups: those who completed less than two workouts/week and those who completed more than two per week. The groups did not differ significantly with regard to any of the variables measured prior to training, suggesting that pre-training fitness was not a major contributing factor to the large subject 'drop-out.' The subjects reported that leaves and temporary duty assignments were more responsible for their inability to maintain two workouts/week.

Physical characteristics. Significant decreases in skinfold thickness were observed at all measured sites except the triceps and thigh (Table 2). Increased circumferences were measured after training for the chest, relaxed and contracted biceps, forearm, and neck (Table 2). These results, together with the increased body density, suggest that muscle hypertrophy was induced by training causing an increased LBM. This was accompanied by a small, but significant decrease in % body fat. These anthropometric changes were not limited to a specific muscle group or body part but were generalized to both the upper and lower body (Table 2). Somatograms were drawn based on the mean values for the various anthropometric measurements (9). The somatograms graphically depict the relative deviation of the mass of selected body areas from normal values for 20-24 years-old North American Caucasian males (9). Figure 5 shows that the greatest change in estimated body mass occurred in the area of the upper arms after training.

Muscle strength. Table 3 shows that there were significant increases in maximal force and peak torque after training for most of the muscle groups tested. Where statistically significant changes were observed, the mean relative increases in strength ranged from 7 to 17 percent, depending on the muscle group and angular velocity of contraction. The greatest increases were evident for the squats at 10 °/s, isometric knee extension, and the bench press at 45 °/s.

Maximal aerobic power and capacity. VO_2max expressed relative to body weight and MAP increased by 9% and 5%, respectively (Table 4). The increase in VO_2max was also significant when expressed in L/min or relative to LBM. A more marked change was noted in the blood lactate response to submaximal exercise; lactate accumulation was 24% less after training (Table 4). All of these changes were statistically significant.

Muscular endurance and anaerobic power. Peak power during the Wingate Test did not change after training, neither in absolute terms nor when expressed relative to body weight. Mean power during the 30-s test was higher after training when expressed relative to body weight (Table 5). This resulted in a higher percentage of peak power being maintained during the final 5 s of the Wingate Test after training than before training. Although these changes were statistically significant, they were so small as to be of little significance with regard to actual muscular endurance.

Maximal expiratory pressure. The mean($\pm$SD) values were 208$\pm$29 and 209$\pm$39 mm Hg before and after training, respectively ($p>0.05$). The individual data ranged from 160-256 mm Hg before training and from 150-264 mm Hg after training. The absolute values were weakly, but significantly correlated with some of the strength measures. However the change in maximal expiratory pressure was not related to the change in any of the strength variables.

DISCUSSION

The main objective of the present investigation is to document the changes of selected physical fitness components in subjects who trained for 12 weeks according to a program designed by DPERA. A prime goal of this training program is to enhance the ability to withstand the physical stress caused by the high acceleration forces to which pilots may be exposed while flying high performance aircraft. This stress affects the central circulatory system (i.e. heart and lungs) (14) as well as the muscles which are recruited to perform straining maneuvers (L-1 and/or M-1) (16). It is primarily the leg and trunk muscles which are recruited for these maneuvers. Preliminary experiments in Sweden have shown that electromyographic activity is relatively high in the stomach and thigh musculature when straining maneuvers are performed in the human centrifuge (15).

The pooling of blood in the lower extremities during exposure to $+G_z$ forces impairs blood return to the heart and the ability to oxygenate the brain. Leg and abdominal muscle contractions can aid in resisting the increased pressure of the hydrostatic blood column which forces blood in a head to foot direction during $+G_z$ acceleration (16). Since straining maneuvers are intermittent isometric contractions, it would require less relative exertion to produce a given absolute force if maximal isometric strength was increased. Likewise, the time during which a given absolute force level can be maintained isometrically is increased after strength training (17). Assuming that the maintenance of blood pressure during exposure to acceleration forces can be directly affected by the pressure exerted against the outer walls of blood vessels by skeletal muscles, that same absolute force can be exerted with relatively less effort after strength training. The preceeding explanation provides a brief physiological background for the theoretical benefits of strength training and the rationale for our evaluation of muscular strength.

Although there were significant increases in strength in the present study they were not as great as have been reported for other strength training studies. The number of training sessions completed during the 12 weeks averaged 32.5±5.9, and ranged from 24-42. The relative increase in strength expressed per training session ranged from 0.03 - 0.52 %/training session. These values are similar to those recently reported by Petersen et al. (18) whose subjects also trained on Hydra-gym equipment, four times weekly for five weeks with a 1:3 work-relief ratio. In contrast, using an almost identical training circuit, Lee (19) reported relative increases in peak torque during isokinetic knee extensions of about 20% at an angular velocity of 180°/s for university students. At a similar angular velocity only a 7% improvement was measured after training in the present study. The subjects in the present study were markedly older than those employed in most strength training studies and this may have contributed to relatively small increases in strength. In a study by Epperson et al. (1,20), the subjects were aircrew who had just completed basic training. They trained for three months with free weights using a typical routine of 3 sets, 10 repetitions per set, with weights which were 70-80% of the maximum weight that could be lifted 10 times. They observed relative increases in strength of 26-40% for various muscle groups. Tesch et al. (2) trained pilots for strength using isotonic weight machines and observed that peak torque increased by 17% during knee extension measured isokinetically at 30°/s and by 13% at 300°/s.

The relatively small increases in strength observed in the present study were probably due to the work:rest ratio. Far greater increases can be expected if longer intervals intervene between sets to permit greater recovery from local muscular fatigue before commencing the next set (for review see refs. 21,22). The relatively small increases in strength may also be related to the marked increases in maximal aerobic power and other indicators of endurance fitness. The

improved aerobic fitness may have occurred at the expense of increases in muscular strength. Hickson (23) demonstrated that combined strength and endurance training can slow down the rate of increase in strength, in contrast to engaging in only strength training. Physiologically, there are several mechanisms involved in adaptations to endurance training which might act antagonistically or competitively with adaptations to strength training. For example, muscle fibers hypertrophy with prolonged strength training and maximal strength is directly related to the cross-sectional area of a muscle (24). In contrast, with endurance training it would be advantageous for mean muscle fiber area to decrease (25). This decreases the diffusion distance from blood capillaries surrounding muscle fibers facilitating the entry of nutrients into the muscle cell and the removal of metabolic end products such as lactic acid. The combination of endurance and strength training could cause a competitive process resulting in a reduction in the normal muscle hypertrophy and associated improvement in strength usually induced by strength training, such as was observed by Hickson (23).

Since the only form of physical training that has been shown to be related to $+G_z$ tolerance is strength training (1), it would seem logical to try to concentrate on this physical fitness component. Slight modifications in the design of the circuit which increase 'rest' time, increase the resistance setting on the Hydra-Gym, and/or decrease the exercise time for a given muscle group would thus be advisable. This recommendation is based on the demonstration that endurance training does not improve $+G_z$ tolerance, and that it might result in impaired tolerance. (1). The theoretical basis for impaired tolerance after endurance training could be a function of the profiliferation of capillaries induced by training (25). Such an increased capillarization enlarges the potential volume for blood pooling during $+G_z$ acceleration. In contrast, prolonged strength training reduces capillary density per unit of muscle area (26), decreasing the relative volume for blood

pooling. In its present form the training circuit used in the present study will cause subjects to train at an average metabolic rate approaching 50% VO_2max (27), so the improvements observed in the aerobic fitness parameters are not surprising.

The training circuit in the present study did not have a specific station for abdominal muscle training. For this reason, abdominal muscle strength was not included as a test variable in the test battery. The importance of abdominal muscle strength with regards to $+G_z$ tolerance is attested to by the results of Epperson et al. (20). They reported significant correlations between abdominal muscle strength and SACM endurance time in the centrifuge as well as between arm curl strength and SACM endurance time. Although various stations in the present training circuit undoubtedly result in some recruitment of stomach musculature, serious consideration should be given to including a specific station for training of the abdominal muscles.

The L-1 and M-1 straining maneuvers are similar in nature to performing the maximal expiratory pressure test used in the present study. Maximal expiratory pressure has been used previously to evaluate respiratory muscle strength (28). These same muscles are probably recruited to perform the straining maneuvers during $+G_z$ acceleration in order to increase intra-thoracic pressure (16) which should aid in resisting the downward hydrostatic pressure of the blood column during $+G_z$ exposure. Tesch (15) has recently reported that maximal expiratory pressure may be related to the strength of larger muscle groups. If there is a relationship between strength and the capacity to generate expiratory pressure, one would expect an increase in the maximal expiratory pressure after strength training. This was not the case in the present study suggesting either that the test is not related to muscular strength or that the strength training was not sufficient to induce changes.

Repeated straining maneuvers, such as occur during a SACM, result in extremely high blood lactic acid concentrations (2). The acidosis which accompanies increased circulating and intramuscular levels of lactic acid is well documented as being associated with muscular fatigue and impaired force production during maximal voluntary contractions (29). Enhanced muscular endurance would, therefore, increase the ability of the musculature to tolerate higher levels of acidosis without the accompanying fatigue. This discussion is the basis for our evaluation of muscular endurance in the present study. The negligible changes in the Wingate Test variables suggest that muscular endurance was not increased in the thigh musculature after training. Alterations in the exercise:rest time ratio and/or in the resistance settings could, once again, be incorporated to emphasize this fitness component.

The operational specifications of the CF-18 and plans for future fighter aircraft (3) all indicate that not only is the absolute $+G_z$ level to which the pilot is subjected likely to be extremely high, but the rate of onset of $+G_z$ forces is also likely to be extremely high. With slower rates of onset of $+G_z$ forces, physiological cues such as gradual loss of peripheral vision (30), could be used as indicators of approaching G-induced loss of consciousness. The higher rates of onset may not allow enough reaction time to respond to these cues and to avoid disaster. Thus, any advantage gained by increased strength will be useless if that muscular force cannot be generated rapidly. Future research should address the trainability of this particular aspect of strength, i.e. the rate of force development during maximal muscle contractions.

Previous strength training studies have demonstrated that improvements in strength are greatest when strength is tested at the same angular velocity at which training occurred (18,31). The increase of strength at faster velocities is very limited (18,31). This is the rationale for our testing of muscular strength at

various angular velocities. In the present study, significant increases in strength were observed at both slow and fast velocities for most of the muscles tested. The question remains whether the increases at the higher contraction velocities could not have been further improved by adjusting the resistance settings on the Hydra-Gym equipment to permit maximal force generation at higher velocities.

CONCLUSIONS

1. The training program described in this report induced rather small, but significant, increases in the maximal strength of several large muscle groups.

2. The training program described in this report induced significant improvements of indicators of endurance fitness.

3. A review of strength training studies suggests that the increases in strength measured in the present study could be enhanced with alterations in the exercise:rest ratio, the number of repetitions performed per set, and/or the resistance settings.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. The effects of any proposed strength training program should be evaluated in terms of the maximal rate of force development and not only the maximal strength.

2. The maximal expiratory pressure test should be validated as an indicator of maximal intrathoracic pressure that can be voluntarily generated during straining maneuvers. The test in its present form is extremely simple to administer and would prove valuable in future human experimentation dealing with the ability to withstand $+G_z$ acceleration, assuming the test is reflective of actual pressure in the chest cavity.

3. If it is decided that some aerobic training is desirable in an exercise program for high performance aircraft crew, research should be carried out to determine the optimal combination of strength and endurance training, with regard to frequency, intensity, and duration, in order to minimize potential impairments of the rate of strength improvement.

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Figure 1.

Illustration of bench press on the ACE multi-function apparatus.

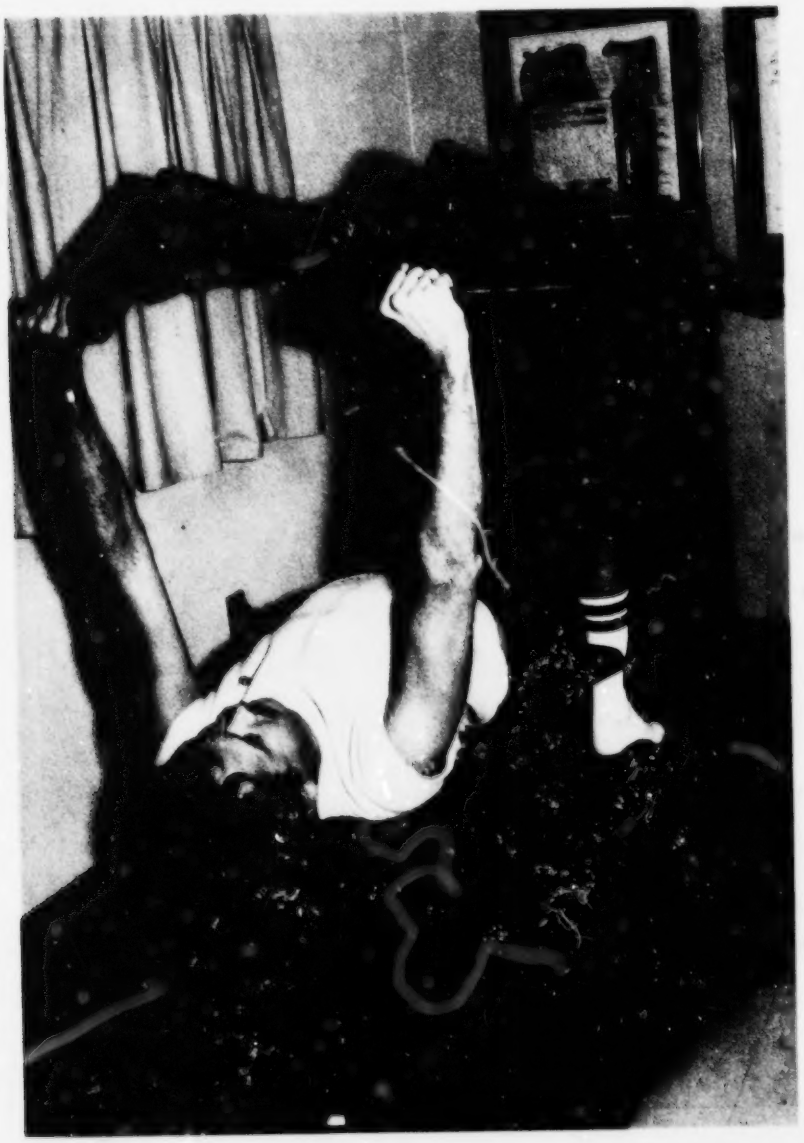

Figure 2.

Illustration of squats performed on the ACE multi-function apparatus.

Figure 3.

Illustration of biceps curls performed on the ACE multi-function apparatus. The back of the upper arm was stabilized against the bar across the chest throughout the motion.

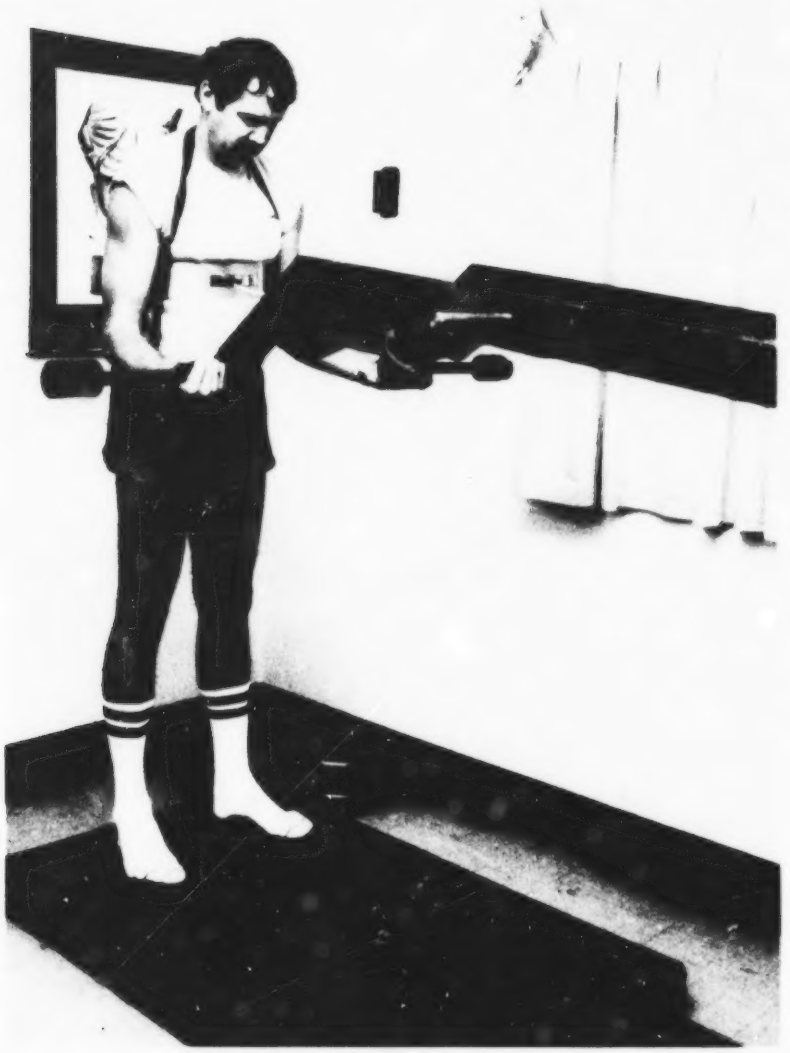

Figure 4.

Knee extension and flexion being performed on the ACE arm-leg apparatus.

ANNEX A

INDIVIDUAL PROGRESSION PERFORMANCE CRITERIA

METHOD: After each workout, individual performance will be assessed and resistance setting amended, based on attainment of pre-selected repetition goals. This process will continue as long as the experimental subject performes at pre-selected goals or until maximum cylinder selector ("6") has been achieved.

Exercise Station	Start	Increase Cylinder Selector if Repetitions Meet or Exceed 20:40 secs	30:50 secs
JUMP SQUAT	1	20	30
	5	12	18
	3	16	24
NECK MACHINE F/B		As many as possible in exercise period.	
BENCH PRESS	1	20	30
	5	8	12
	3	14	22
BICEPS/TRICEPS	1	28	42
	5	12	18
	3	20	30
NECK MACHINE S/S		As many as possible in exercise period.	
BILATERIAL QUAD/HAM	1	20	30
	5	10	15
	3	18	24
SHOULDER PRESS	1	20	30
	5	8	12
	3	14	21
UPRIGHT ROW	1	20	30
	5	8	12
	3	14	21

Table 1. Genders and trades of participating subjects.

	Males		Females	
	Aircrew	Non-aircrew	Aircrew	Non-aircrew
Pre-training	33	7	3	2
Post training	14	4	-	2

Table 2. Anthropometric measurements before and after 12 weeks of circuit training. The % body fat and lean body mass (LBM) were calculated based on body density determined during hydrostatic weighing.

Variable	Pre-Training Mean	Pre-Training SD	Post-Training Mean	Post-Training SD	% Change
Weight, kg	81.3	15.3	80.6	14.5	-1.0
Body fat, %	17.9	6.9	16.3	6.6	-2.2**
LBM, kg	66.0	8.9	66.8	8.5	-1.2*
Skinfolds, mm					
biceps	6.7	3.2	5.3	2.7	-21.0***
triceps	12.3	5.9	11.7	5.0	-4.9
subscapular	15.9	8.5	14.8	7.5	-6.9*
suprailiac	20.8	12.1	18.2	9.3	-12.5*
abdomen	25.7	11.3	20.0	7.4	-21.6***
thigh	16.4	7.2	15.0	5.4	-8.5
calf	12.8	5.1	10.8	3.8	15.6*
Circumferences, cm					
chest	97.4	8.0	99.2	7.0	1.8**
shoulders	116.7	8.7	117.4	8.3	0.6
relaxed biceps	29.2	2.7	31.2	2.6	6.8***
contracted biceps	33.3	3.2	34.7	3.3	4.2***
forearm	27.9	2.5	28.5	2.3	2.2***
abdomen	88.0	14.0	87.8	12.7	-0.2
thigh	58.6	5.5	59.0	5.0	0.7
calf	38.3	2.9	38.1	2.7	-0.5
neck	36.6	3.9	38.6	3.0	5.5**

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table 3. Peak force or torque during maximum voluntary contractions in 20 subjects before (pre) and after (post) 12 weeks of training.

Exercise	Angular Velocity °/s	Pre Mean	Pre SD	Post Mean	Post SD	% Change
Squats, kg	10	170.6	36.7	199.5	35.0	17.4***
	45	84.4	18.9	93.9	19.1	17.2***
Bench press, kg	10	81.5	18.7	87.5	17.2	7.4*
	45	37.3	8.4	43.7	8.7	17.2***
Biceps curls, kg	0	40.8	5.6	38.2	6.6	-6.4
	10	47.1	9.4	47.9	9.1	1.6
	45	26.4	4.7	28.4	5.3	7.6**
Knee extension, Nm	0	245	66	280	76	14.3***
	30	195	36	208	34	6.7*
	100	173	33	190	33	9.8***
	200	146	27	159	23	8.9***
Knee flexion, Nm	30	124	26	128	22	3.2
	100	116	20	125	24	7.7***
	200	105	18	112	20	6.7*

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table 4. Maximal aerobic power and capacity variables before and after 12 weeks of circuit strength training. The maximal aerobic power load (MAP) is the highest power output that could be maintained for 1 min during the $\dot{V}O_2$max test. The submaximal lactate concentration was determined after 5 min exercise against a standardized resistance.

Variable	Units	Pre		Post		% Change
		Mean	SD	Mean	SD	
VO2max	l/min	3.310	0.505	3.618	0.594	9.3***
	ml/kg-min	42.8	7.3	46.7	7.7	9.1***
	ml/kg LBM - min	50.6	7.1	54.5	7.5	7.7***
MAP	W	294	44	309	52	5.1*
Submax lactate	mmol/L	6.2	2.2	4.7	2.2	-25*

* $p<0.05$; *** $p<0.001$

Table 5. Wingate Test measurements before and after 12 weeks of training. The values are expressed absolutely and relative to body weight.

Variable	Units	—Pre— Mean	SD	—Post— Mean	SD	% Change
Peak power	W	802	152	807	136	0.6
	W/kg	10.2	1.4	10.2	1.1	0.0
Mean power	W	597	120	612	112	2.5
	W/kg	7.6	1.2	7.8	1.0	2.6*
Fatigue	%	51	11	55	9	7.8*

* $p<0.05$

Figure 5.

Somatogram of the subjects before and after training showing the deviation of selected body masses from normal values.